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1. PURPOSE

The objective of this calculation is to evaluate the criticality risk in the surface facility for design basis events (DBE) involving Department of Energy (DOE) Spent Nuclear Fuel (SNF) standardized canisters (Civilian Radioactive Waste Management System [CRWMS] Management and Operating Contractor [M&O] 2000a). Since some of the canisters will be stored in the surface facility before they are loaded in the waste package (WP), this calculation supports the demonstration of concept viability related to the Surface Facility environment. This calculation was prepared in accordance with the development plan *"DBE Criticality Analyses on DOE SNF"* (CRWMS M&O 2000b).

The scope of this calculation is limited to the consideration of three DOE SNF fuels, specifically Enrico Fermi SNF, Training Research Isotope General Atomic (TRIGA) SNF, and Mixed Oxide (MOX) Fast Flux Test Facility (FFTF) SNF.

This calculation was prepared in accordance with the Administrative Procedure AP-3.12Q, Rev. 0, ICN 2, *Calculations*.

2. METHOD

Criticality is characterized by the effective neutron multiplication factor (k_{eff}), which is calculated using the Monte Carlo neutron transport code MCNP Version 4B2 code (Briesmeister 1997). This calculation is performed using continuous energy cross-section libraries from the Evaluated Nuclear Data File (ENDF), which is part of MCNP software.

With regard to the development of this calculation, the control of the electronic management of data was evaluated in accordance with AP-SV.1Q, *Control of the Electronic Management of Information*. The evaluation (CRWMS M&O 2000d) determined that the current processes and procedures are adequate for the control of electronic management of data for this activity.

3. ASSUMPTIONS

3.1 It is assumed that the canisters are stored in a fixed geometry of 2 by infinite array in the surface facility. The rationale for this assumption is that the numbers of canisters stored are limited by design in 2 by 10 having fixed positions under DBEs (Mattsson 2000, p. 18). This assumption is used throughout Section 5.

3.2 It is assumed that the crane can transport only one canister at a time. The rationale for this assumption is that it prevents collision between canisters (CRWMS M&O 2000a, p. 4). This assumption is used throughout Section 5.

3.3 It is assumed that all the misload events occur as the result of crane failure. The rationale for this assumption is that administrative controls will prevent placement of any canister outside of designated locations (CRWMS M&O 2000a, p. 4). This assumption is used throughout Section 5.

3.4 It is assumed that the canisters are dry internally. This assumption is based on the fact that the canister is sealed after loading, and Waste Acceptance System Requirements Document (WASRD) (DOE (U.S. Department of Energy) 1999c, p.15) disallows the presence of any significant amount of liquid with the SNF. This assumption is used throughout Section 5.

3.5 The technical information related to the DOE SNF canister and fuel dimension, and the material composition of the DOE SNF considered in this calculation, which are taken from *FFTF (MOX) Fuel Characteristics for Disposal Criticality Analysis* (DOE 1998), *TRIGA (UZrH) Fuel Characteristics for Disposal Criticality Analysis* (DOE 1999a) and *Fermi (U-Mo) Fuel Characteristics for Disposal Criticality Analysis* (DOE 1999b), is only used to determine the bounding values and used as reference only. The basis for this assumption is that these are the best sources of technical information available and they are provided by the National Spent Nuclear Fuel Program to support the disposal of the DOE-owned SNF in the potential Monitored Geologic Repository at Yucca Mountain.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE

The MCNP code is used to calculate the k_{eff} of the storage canisters. The software specifications are as follow:

- Software name(s): MCNP
- Software version/revision number(s): Version 4B2
- Computer Software Configuration Item: 30033 V4B2LV (CRWMS M&O 1998a)
- Computer type: Hewlett Packard (HP) 9000 Series Workstations
- Computer processing unit number: Software is installed on the CRWMS M&O workstation, CRWMS M&O tag number 700887

The input and output files for the various MCNP calculations are documented in Attachment I. The calculation files described in Sections 5 are such that an independent repetition of the software use may be performed. The MCNP software used was obtained from the Software Configuration Management, in accordance with the appropriate procedures and it is used only within the range of validation as documented in CRWMS M&O 2000d. The names of the electronic copies of the MCNP4B2 input and output files are provided in Attachment I.

4.2 SOFTWARE ROUTINES

None used.

4.3 MODELS

None used.

5. CALCULATIONS

The criticality calculations are performed for DOE SNF canisters loaded, in all cases, with intact fuels. The canisters are considered loaded with three kinds of SNF. The DBEs calculation referred to in this document corresponds to canister-related group events from *Design Basis Events with Criticality Potential in the Surface Facility* (CRWMS M&O 2000a, p. 4).

5.1 SURFACE FACILITY CRITICALITY CALCULATIONS

A detailed design for the surface facility has not yet been developed. As a result, various options are investigated to identify bounding configurations for which DBEs will be considered. These calculations are done considering the canisters loaded with three kinds of SNF. The first fuel is Enrico Fermi SNF, which is the fuel with highest uranium loading in the DOE SNF canister (CRWMS M&O 1999b, and CRWMS M&O 1999b output file "ilwfg.o"). The second fuel is MOX FFTF SNF, plutonium loaded (CRWMS M&O 1999a, and CRWMS M&O 1999g, output file "6packd0_ss_10+"), and the third fuel is Uranium Zirconium Hydride (UZrH) TRIGA SNF (CRWMS M&O 1999c, and CRWMS M&O 1999f, output file "int12a").

The files used in this calculation to create the input file for MCNP are provided by CRWMS M&O 1999b, CRWMS M&O 1999f, and CRWMS M&O 1999g, which are used as reference only. These files are used, in this document, as a reference to create the new MCNP input file.

Canisters could be stored on a concrete floor, close to a concrete wall and in array of two by ten (Mattsson 2000, p. 18) canisters. An infinite array of canisters along a wall is used in this calculation for conservatism in evaluating DBEs (See Figure 5-2).

All canister-related events that involve a single canister have no criticality concerns, since criticality has been precluded by design. (CRWMS M&O 2000a, p. 5).

5.1.1 Single Canister Calculation

A single canister inside of a parallelepiped with dimensions 46 cm, 46 cm, and 300 cm (XYZ), with reflected conditions in the X and Y directions is considered. The purpose of this calculation is to demonstrate the k_{eff} for an infinite number of canisters. Figure 5-1 shows the unit configuration considered. The results for these configurations corresponding to Enrico Fermi, FFTF and TRIGA SNF are shown in Table 6-1 in Section 6.1.

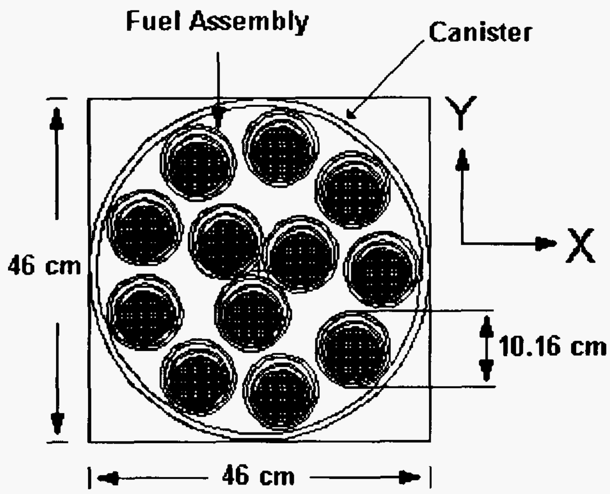


Figure 5-1. Single Enrico Fermi Canister under Reflected Conditions in the X and Y Directions

5.1.2 Concrete Influence on k_{eff}.

The configuration investigated represents an infinitely long array two canisters deep sitting on a concrete floor and against a concrete wall. Since the concrete composition for the facility wall and floor is unknown, various concrete compositions are investigated to determine the sensitivity to likely variations. Four different concrete compositions were used to perform this investigation: Magnuson, Oak Ridge, Regular, and Rocky Flats concrete. The concrete compositions and densities are obtained from the SCALE Manual (NRC 1995, Volume 3, Section M8, p. M8.2.4). The results of these sensitivity calculations are presented in Table 6-2, in Section 6.2.

5.1.3 Corner and Stainless Steel Influence on k_{eff}

Different storage scenarios are investigated considering the canisters stored in a corner of the room, and the effects of the stainless steel plate on the walls and floor. The stainless steel could also represent the bottom and sides of a rack to hold the canisters. The purpose of these calculations is to demonstrate the highest k_{eff} for a dry storage configuration, considering the influences of the possible surroundings. Several cases are run varying the number of canisters stored. The reflected condition for neutrons under an infinite array (in X direction) and the reflected condition for only one X and Y direction were also calculated. The ceiling is neglected as it is considered far enough away for the neutrons to be lost. Magnuson's concrete is used. See Figure 5-2. The results are presented in Tables 6-3 and 6-4 in Section 6.3.

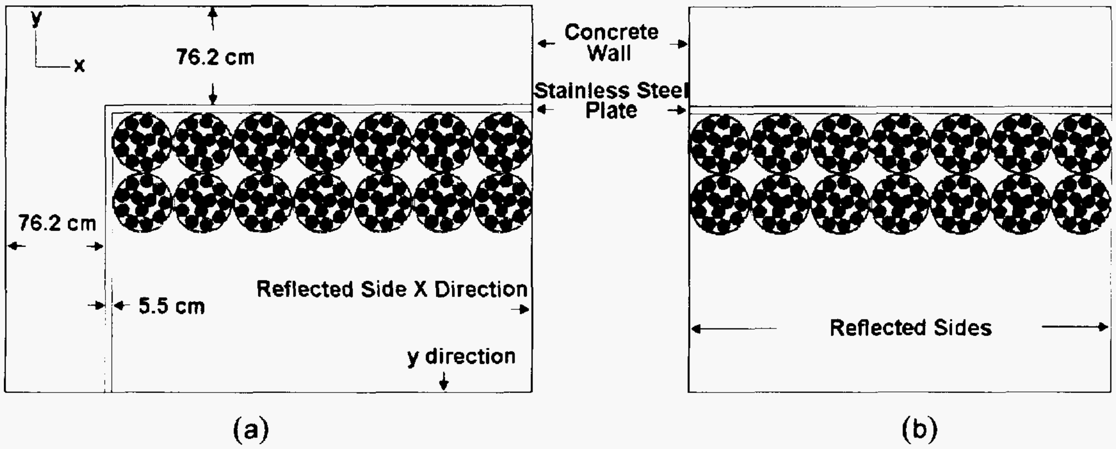


Figure 5-2. Canister Storage in the Corner (a) and Canisters in an Infinite Array (b).

5.1.4 Optimum Moderation

The introduction of water to the facility is considered a beyond design basis event (BDBE). This BDBE is considered to demonstrate margin.

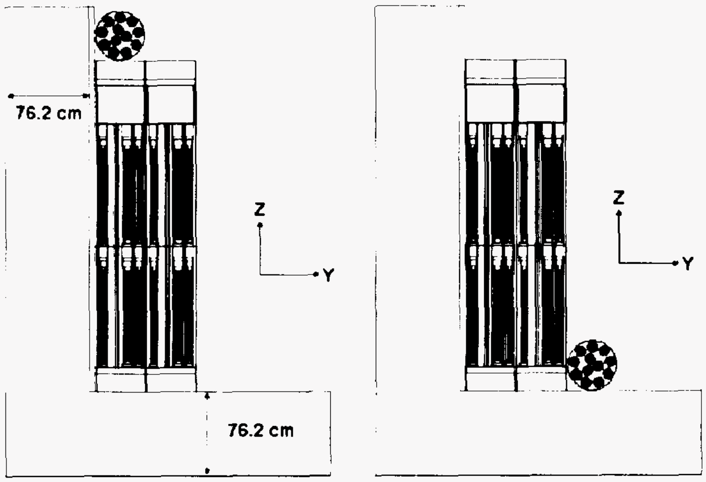
The most reactive configuration in Section 5.1.3 it is used to determine the optimum moderation. The calculations vary the density of the water from 0.01 to 0.9 g/cm^3. A configuration where the canisters are placed in recessed positions in a concrete floor is also considered. These results are presented in Table 6-5 and Table 6-6, in Section 6.4.

5.1.5 DBE Events

This section investigates a tipover events or slapdown and drop event, using the most reactive configuration (the optimum moderation and the most reactive concrete composition determined in Sections 5.1.2 through 5.1.4). These events require a failure of the crane during transfer of the canister from the shipping cask to the disposal container (DC). Since the canisters will never be purposely disengaged from the crane, unless they are in shipping cask or the DC, and since only one canister is transferred at a time, the only configuration of concern involves a tipover or drop over the cask, or a slapdown, drop and tilt on the floor. (CRWMS M&O 2000a, p. 4)

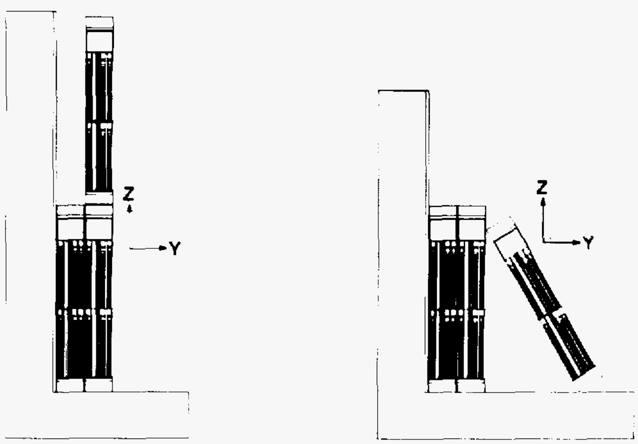
Several cases are considered. The tipover event corresponds to a canister lying down on top of the array, or lying down on the side of the array (CRWMS M&O 2000a, p. 4), as shown in Figure 5-3(a) and Figure 5-3(b). The drop event corresponds to a canister standing up on the top of the canister array, as shown in Figure 5-4(a), or a canister standing up on the floor, close to the canister array (CRWMS M&O 2000a, p. 4). The tilt event (Figure 5-4[b]) is similar to a drop event, but the canister is tilted between the canister array and the floor.

The most reactive configuration and the most reactive components determined in the previous sections are used to perform the criticality calculation. These results are presented in Table 6-7 and Table 6-8 in Section 6.5.



(a) (b)

Figure 5-3. Canisters Stored Parallel to the Concrete Wall with one Canister Lying Down (a) on Top of the others and (b) on the Ground Close to the others.



(a) (b)

Figure 5-4. Canisters Stored Parallel to the Concrete Wall with a Single Canister: (a) on Top and (b) in Tilt Position.

5.1.6 Maximum Number of Canisters in the Y direction

The maximum number of canisters that can be stored in the Y direction is investigated in this section, considering an infinite array in the X direction (see Figure 5-5). In order to optimize neutronics coupling, the canisters are configured with no space between them. The objective is to find a bounding array of the canisters that can be placed together without exceeding the interim critical limit. Although the canisters will be stored in an array of two, it is useful to know the maximum canisters that can be stored in the Y direction. The configuration with three canisters in the Y direction bounds any DBE involving the introduction of another canister next to an infinite array of canisters. These results are presented in Table 6-9 in Section 6.6.

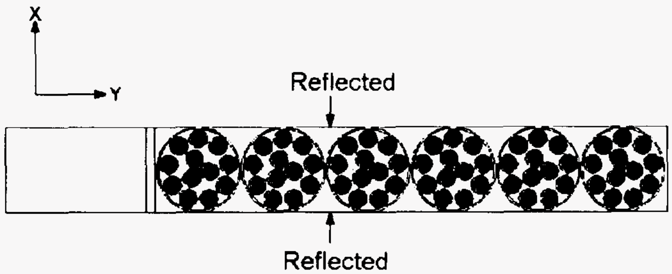


Figure 5-5. Maximum Canister Line-up in the Y Direction.

5.1.7 Canisters Inside the Cask

The canisters will be transported inside a cask. The purpose of this calculation is to evaluate the effect on k_{eff} of DBEs involving a cask or similar configuration. The cases investigated here correspond to canisters inside the stainless steel cask, and canisters without the cask, which represent another possible storage configuration. Both cases are considered with one canister lying down on top of the cask or canisters, as shown in Figure 5-6. In both cases, the cask basket is neglected for conservative reasons. These results are presented in Table 6-10 through Table 6-13, in Section 6.7.

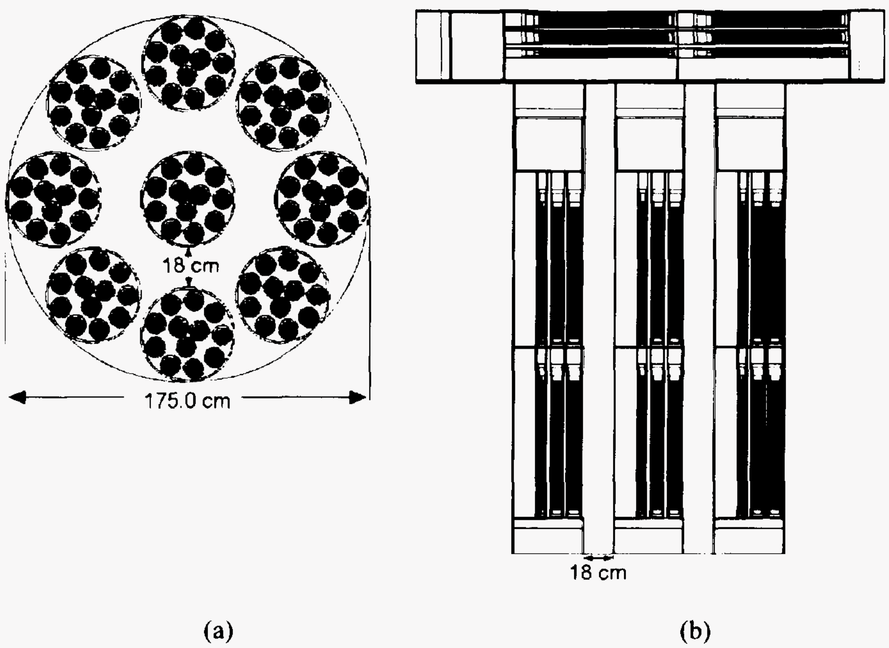


Figure 5-6. Cask loaded with (a) a central canister surrounded by eighth canisters, and (b) a central canister surrounded by eight canisters, with one canister lying down on the top.

5.2 DOE SNF CANISTER SPECIFICATIONS

The short canister, used for the codisposal of Enrico Fermi and TRIGA SNF, is a circular cylinder of stainless steel (Type 316L). The canister has a 457.2-mm (18.0-in) outer diameter (OD) with a 9.525-mm (0.375-in.) wall thickness. The minimum internal length of the canister is 2540 mm (100 in.) and the nominal overall length is 3000 mm (118.11 in.). The canister maximum total weight is 2270 kg. There are curved-bottom, carbon steel rupture disks that vary in thickness from 15.24 mm to 50.8 mm at the top and bottom boundaries of the canister. The curved-bottom, carbon steel rupture disks are represented in this calculation by 33-mm thick ([50.8 + 15.24]/2) plates. (DOE 1999a, p. 27 and DOE 1999b, p. 10)

The long canister is used for the codisposal of MOX FFTF SNF, and is also a circular cylinder of stainless steel (Type 316L). The dimensions are a 457.2-mm (18.0-in.) OD with a 9.525-mm (0.375-in.) wall thickness. The nominal length of the canister is 4145 mm (163.2 in.), the nominal overall length 4569 mm (179.87 in.). Curved bottom carbon-steel impact disks that vary in thickness from 15.24 mm to 50.8 mm are located at both the top and bottom of the canister. In addition, there is a 12.7-mm thick curved plate and a 12.7-mm thick flat plate in each end of the canister. (DOE 1998, pp. 6, 7)

For Enrico Fermi, the DOE 18-inch canister is a stack of two sets of 4-inch OD tubes. Twelve tubes, welded to a base plate, comprise each set. A shipping canister made of aluminum and referred as –01 canister is contained in each tube. Each –01 canister contains an aluminum canister, referred to as the –04 canister. The –04 canister contains 140 SNF pins from the Enrico Fermi fast reactor. The fuel pins have zirconium clad and are derodded. (CRWMS M&O 1999b, p. 8). The Enrico Fermi WP require 14.5 kg (3%, by volume) of $GdPO_4$ uniformly distributed in the iron shot-$GdPO_4$ filler. (CRWMS M&O 2000f, spreadsheet "new_intact_pipes" and CRWMS M&O 2000e, p. 80).

The DOE SNF canister for TRIGA fuels contains three baskets, each containing 37 fuel elements. Stainless steel tubes with 2.96 kg of Gd are welded together at the top and the bottoms of the tubes are welded to a steel base plate. Three such basket assemblies are stacked in the SNF container to provide a total of 111 elements, with a total of 8.9 kg of Gd per container. (CRWMS M&O 2000c, p. 85).

The DOE SNF canister for FFTF fuels contains six basket locations, one center position surrounded by five outer positions. Either an Ident-69 fuel pin container or a driver fuel assembly (DFA) can be placed in the center position. All outer positions are filled with DFAs only. Maximum loaded weight of the canister is 2721 kg.

The basket for the FFTF fuel, which has a 2.75 wt% of Gd content (CRWMS M&O 1999e, p. 80), consists of a cylindrical center tube and five divider plates extending radially from the center tube to the DOE SNF canister wall. The center tube is made of stainless steel (Type 316L) with 153 mm inside diameter and 10 mm wall thickness. The divider plates are also made of stainless steel (Type 316L) with a 10 mm thickness. The basket height is 4125 mm. (CRWMS M&O 1999e, p. 7)

5.3 MATERIALS AND FUEL DESCRIPTION

Basic information such as dimensions and compositions for each fuel type is given in this section. For more details about these fuels, see the references.

5.3.1 Enrico Fermi Fuel Pins Dimensions

The zirconium-clad fuel pins are 30.5 in. long (fuel matrix length). The diameter of the fuel matrix is 0.148 in. and the OD of the clad is 0.158 in. There is no gap between the fuel and the clad. For more detail see "*Fermi (U-Mo) Fuel Characteristics for Disposal Criticality Analysis*" (DOE 1999b, p. 2)

Table 5-1 shows the composition of an Enrico Fermi fast reactor fuel pin. The composition of the fuel is that of fresh (non-irradiated fuel), as no credit is taken for the burnup (25.69 wt% U-235 enrichment) (CRWMS M&O 1999b, p. 9).

Table 5-1. Composition of an Enrico Fermi Fast Reactor Fuel Pin (Fresh Fuel)

Element/Isotope/Impurities	Mass (g)	Weight Percent in Fuel Pin (No Clad)
U (U-235 & U-238)	133.9	-
U-235	34.4	22.96[a]
U-238	99.5	66.41[a]
Mo	15.31	10.63[a]
Impurities	0.609	-
Total (U+Mo +Impurities)	149.819	-
Zr Cladding	9.2	-

NOTES: [a] Calculated value.
SOURCE: CRWMS M&O 1999b, p. 9

The density of the fuel with no clad is 17.424 g/cm^3 (CRWMS M&O 1999b, p. 9)

5.3.2 TRIGA Fuel Rod Dimensions

As a fine metallic dispersion in the zirconium hydride matrix, TRIGA fuel contains different uranium loading. The hydrogen to zirconium (H/Zr) atom ratio is nominally 1.6 (in the face-centered cubic delta phase), although earlier fuels used a H/Zr atom ratio of 1.0. The highly enriched version of TRIGA fuel (discontinued after 1979), as well as new fuels with higher loadings of low enriched uranium contains up to about 3 wt% erbium as a burnable neutron absorber. (CRWMS M&O 1999c, p. 15)

The TRIGA elements contain fuel rods with a homogeneous mixture of uranium and zirconium-hydride. A fuel composition is identified by an indicator such as U20ZrH1.6. This means that the uranium is 20 wt% enriched U-235 with a H/Zr atom ratio of 1.6. The fuel rods may also contain the burnable neutron absorber erbium. Aluminum-clad TRIGA is referred to as TRIGA-Al, stainless steel-clad TRIGA as TRIGA-SS, and Incoloy-clad TRIGA as TRIGA-In. In this calculation, only TRIGS-SS is used. (CRWMS M&O 1999c, pp.15-16)

There are four types of TRIGA-SS rods; namely, standard streamline, standard plain type, four-rod cluster, and Annular Core Pulsed Reactor (ACPR) types. All TRIGA-SS rods have a 38.1-cm (15.0-in.) length and are clad with 0.0508-cm (0.02-in.) thick stainless steel. A 0.5715-cm

(0.225-in.) diameter zirconium rod is placed in a 0.635-cm (0.25-in.) diameter hole drilled through the center of the fuel rods. There are five variations for the uranium loading of the standard streamline type rods. For the purpose of these calculations, the fuel TRIGA-SS FLIP is considered. (DOE 1999a, p.19)

The TRIGA-SS FLIP rods are U70ZrH1.6 fuel rods loaded with 137 g U-235, 8.5% of the total mass being uranium. Table 5-2 summarizes the rod loading. (CRWMS M&O 1999c, pp. 15-19)

Table 5-2. Stainless Steel-Clad Fuel Elements Initial Loading

Designation	Initial Uranium Content (wt%)	Initial Uranium Enrichment (wt%)	H/Zr Atom Ration
FLIP	8.5	70.0	1.6

SOURCE: CRWMS M&O 1999c, p. 14

5.3.3 MOX FFTF Rod Dimensions

The FFTF standard DFA contains 217 cylindrical fuel pins and is hexagonally shaped. The assembly is 3657.6 mm long. The overall height of a fuel pin is 2372.36 mm for Types 3.1 and 4.1 fuel pins, and 2377.44 mm for Types 3.2 and 4.2 fuel pins. The stainless steel (Type 316L) cladding is 0.381 mm (0.015 in.) thick. The ID and OD of the cladding are 5.08 mm (0.200 in.) and 5.842 mm (0.230 in.), respectively. Each fuel pin has a 914.4 mm (36 in.) long fuel region containing fuel pellets with an OD of 4.9403 mm (0.1945 in.). The fuel region is centered 1663.7 mm (65.5 in.) from the bottom of the assembly. Each fuel pin is helically wrapped with a 1.4224-mm (0.056-in.) diameter stainless steel Type 316L wire to provide lateral spacing along its length. The wire pitch is 304.8 mm (12 in.). The fuel pins are arranged with a triangular pitch within the hexagonal duct. The fuel pin pitch is 7.2644 mm (0.286 in.). The fuel density is reported as 90.4% of the theoretical density, which corresponds to a fuel pellet density of 10.02 g/cm^3. The MOX ($UO_{1.96}$ and $PuO_{1.96}$) fuel region is followed by 20.32 mm (0.8 in.) of natural UO_2 insulator pellets and 144.78 mm (5.7 in.) of Inconel 600 reflector on each end. The density of natural uranium insulator pellets is 10.42 ± 0.22 g/cm^3. The reflector outer diameter is 4.8133 mm (0.1895 in.). Above the top reflector are a stainless steel Type 302 spring (125.5 mm long by 0.8052 mm in diameter) and a stainless steel Type 316L plenum (862.1 mm long with a 4.9022-mm outer diameter and 0.1397 mm wall thickness). The maximum stainless steel spring volume is 2.7264 cm^3. The fuel pin is closed with top and bottom caps having a 5.842-mm diameter. The length of the top cap is 104.6 mm. The bottom cap length for Type 3.1 and 4.1 fuels is 35.6 mm. The bottom cap length for Type 3.2 and 4.2 fuels is 40.6 mm. Fuel enrichments and isotopic fractions for all four types of fresh FFTF fuel are given in Table 5-1 of CRWMS M&O 1999a.

The DFA is comprised of a hexagonal duct that surrounds the fuel pins, discriminator, inlet nozzle, neutron shield and flow orifice region, load pads, and handling socket. The duct is stainless steel Type 316L with a wall thickness of 3.048-mm (0.12-in.). The duct-tube outer dimension is 116.205 mm (4.575 in.) across the hexagonal flats and 131.064-mm (5.16 in.) across the opposite hexagonal points. The maximum assembly width is determined by the load pads, which are 138.1125 mm (5.4375 in.) wide across the opposite hexagonal points. The assembly is 3657.6 mm (144 in.) high. The total weight of a DFA is 172.819 kg (~381 lb). (CRWMS M&O 1999a, pp. 6, 7).

5.3.4 Concrete Specifications

Four kinds of concrete are used in this calculation. These concrete compositions are well known and they represent a range of possible concrete compositions. Table 5-3 to through 5-6 in this section provide the compositions of Magnuson, Oak Ridge, Regular, and Rocky Flats concrete. This information is taken from the SCALE Manual (NRC 1995, Volume 3, Section M8, p. M8.2.4).

Table 5-3. Magnuson Concrete Composition

Element	wt%	Element	wt%
Fe	0.5595	Ca	22.6318
H	0.3319	Ti	0.1488
C	10.5321	Mn	0.0512
O	49.9430	Si	4.2101
Na	0.1411	S	0.2483
Mg	9.4200	Cl	0.0523
Al	0.7859	K	0.9445
Density		2.147 g/cm^3	

SOURCE: NRC 1995, Volume 3, p. M8.2.4.

Table 5-4. Oak Ridge Concrete Composition

Element	wt%	Element	wt%
Fe	0.7784	Mg	3.265
H	0.6187	Al	1.083
C	17.52	Si	3.448
O	41.02	K	0.1138
Na	0.271	Ca	32.13
Density		2.2994 g/cm^3	

SOURCE: NRC 1995, Volume 3, p. M8.2.4.

Table 5-5. Regular Concrete Composition

Element	wt%	Element	wt%
Fe	1.4	Al	3.4
H	1	Si	33.7
O	53.2	Ca	4.4
Na	2.9	-	-
Density		2.3 g/cm^3	

SOURCE: NRC 1995, Volume 3, p. M8.2.4.

Table 5-6. Rocky Flats Concrete Composition

Element	wt%	Element	wt%
Fe	1.01	K	1.37
H	0.75	Ca	23
C	5.52	S	0.19
O	48.49	Ti	0.1
Na	0.63	N	0.02
Mg	1.25	Si	15.5
Al	2.17	-	-
Density		2.231 g/cm^3	

SOURCE: NRC 1995, Volume 3, p. M8.2.4.

5.3.5 Stainless Steel (Type 316L) Compositions

Table 5-7 provides the composition of the stainless steel plate (Type SS 316L) used in this calculation. This composition was taken from ASTM A 276-91a (ASTM A 276-91a, p. 2, Table 1.). A density equal to 7.98 g/cm^3 was taken from ASTM G 1-90, *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*, p. 7.

Table 5-7. Stainless Steel (Type SS 316L) Composition

Element	wt%	Element	wt%
C	0.03	Cr[a]	17.0
N	0.1	Mn	2.0
Si	1.0	Ni[a]	12.0
P	0.045	Mo[a]	2.5
S	0.03	Fe	65.295

NOTE: [a] Midpoint of the range of wt% provided in reference is reported here.
SOURCE: ASTM A 276-91a, *Standard Specification for Stainless and Heat-Resisting Steel Bars and Shapes*, p. 2.

5.4 BIAS AND UNCERTAINTY IN CRITICALITY CALCULATIONS

The results reported from the MCNP calculations are the combined average values of k_{eff} from the three estimates (collision, absorption, and track length) and the standard deviation of these results (σ) listed in the final summary in the MCNP output. When MCNP under predicts the experimental k_{eff}, the experimental uncertainty is added to the uncertainty at 95% confidence from the MCNP calculation, to obtain bias. This bias, along with the 5% margin is used to determine the interim critical limit for all MCNP calculations.

The worst case bias, calculated from the MCNP, is 0.019. Based on this bias, the interim critical limit is determined to be 0.93 after a five percent margin. This interim critical limit will be used until the final critical limit is established (CRWMS M&O 2000c, pp. 36-38).

6. RESULTS

In this section, the results for the different configurations and scenarios explained throughout Section 5 are presented. Additional information for the cases run for this calculation can be found in Attachment I (Compact Disc).

6.1 SINGLE CANISTER

Table 6-1 shows the results for an infinite array of canisters in the X and Y directions. The results for the Enrico Fermi and FFTF canister arrays indicate that a limit must be placed on the number of canisters that may be placed together because the interim critical limit of 0.93 is exceeded. The TRIGA SNF canister array result falls below the interim critical limit. It is not considered further since the infinite array bounds the results for any of the DBEs, and is bounded by the other two fuels considered.

Table 6-1. A Single Canister with Reflected Condition in X and Y Directions

Fuels	Case Name	Reflected	
		k_{eff}	σ
Enrico Fermi	Out0	0.96533	0.00060
TRIGA		0.79998	0.00070
FFTF		1.06261	0.00070

NOTE: Case name refers to the output file on Attachment I.

6.2 CONCRETE INFLUENCE ON k_{eff}

Table 6-2 shows the different k_{eff} results considering different concrete compositions. These calculations are performed under dry conditions.

Table 6-2. Effect of the Concrete Composition on Criticality

Concrete Name	Case Name	Enrico Fermi		MOX FFTF	
		k_{eff}	σ	k_{eff}	σ
Magnuson	Out14R0Mag	0.75339	0.00057	0.67786	0.00063
Oak Ridge	Out14R0OR	0.73915	0.00063	0.66093	0.00063
Regular	Out14R0Reg	0.72996	0.00056	0.65164	0.00060
Rocky Flats	Out14R0RF	0.73496	0.00060	0.65687	0.00059

6.3 CORNER AND STAINLESS STEEL INFLUENCE ON k_{eff}

Table 6-3 and Table 6-4 show the results for different storage scenarios for Enrico Fermi and FFTF, respectively. The case Out14 corresponds to an infinite array of canisters stored on a concrete floor close to a corner, without stainless steel plates on the wall, as shown in Figure 5-2a. Another case, Out14r is investigated, corresponding to an infinite array of canisters stored on a concrete floor and against a concrete wall far away from a corner, without a stainless steel plate on the wall (see Figure 5-2[b]). A similar set of cases is considered with reflected conditions in both (RBS) X and Y. In the Y direction, the reflected condition is considered only for the opposite side of the wall. These cases are named Out14RBS and Out14rRBS. These cases are noted in Attachment I with the suffix "CC" added to the case name.

A similar set of cases is investigated considering a 5.5-cm thickness of stainless steel plate on the concrete walls and floor. In some cases, the stainless steel floor plate is not considered in the calculation, because it is far from the fuel therefore there is no effect on the k_{eff}. These cases are noted in Attachment I with the suffix "SS" added to the case name.

Table 6-3. Different Storage Scenarios for Enrico Fermi

Cases Name	With Stainless Steel (SS)		Only Concrete (CC)	
	k_{eff}	σ	k_{eff}	σ
Out14	0.75398	0.00059	0.75007	0.00059
Out14r	0.76008	0.00064	0.75561	0.00054
Out14 RBS	0.78589	0.00060	0.78202	0.00062
Out14r RBS	0.80007	0.00057	0.79536	0.00060

Table 6-4. Different Storage Scenarios for MOX FFTF

Cases Name	With Stainless Steel (SS)		Only Concrete (CC)	
	k_{eff}	σ	k_{eff}	σ
Out14	0.67180	0.00060	0.66995	0.00065
Out14r	0.67845	0.00067	0.67786	0.00063
Out14 RBS	0.70981	0.00062	0.70396	0.00065
Out14r RBS	0.72794	0.00064	0.72388	0.00064

6.4 OPTIMUM MODERATION

Table 6-5 shows different k_{eff} results considering different amounts or percentages of water around the canister. The objective of these calculations is to evaluate the optimum moderation among canisters. The density of the water varies from 0.01 to 0.9 g/cm^3.

Out14R+CC corresponds to an infinite array of canisters vertically oriented and buried in a concrete hole. The objective of this calculation is to evaluate the effect of the concrete on k_{eff}.

Table 6-5. Optimum Moderation for Enrico Fermi and MOX FFTF

Case Name	Water Density (g/cm^3)	Enrico Fermi		MOX FFTF	
		k_{eff}	σ	k_{eff}	σ
Out14R+CC	-	0.82026	0.00063	0.75986	0.00067
Out14RSS01	0.01	0.76541	0.00061	0.68738	0.00060
Out14RSS05	0.05	0.77219	0.00061	0.70028	0.00066
Out14RSS1	0.1	0.75796	0.00055	0.68870	0.00068
Out14RSS15	0.15	0.73638	0.00063	0.66698	0.00066
Out14RSS2	0.2	0.71363	0.00061	0.64314	0.00063

Out14RSS3	0.3	0.67423	0.00055	0.60321	0.00062
Out14RSS5	0.5	0.62443	0.00064	0.55327	0.00063
Out14RSS7	0.7	0.59646	0.00059	0.52462	0.00055
Out14RSS9	0.9	0.57669	0.00058	0.50673	0.00060

Table 6-6 shows different k_{eff} results considering case Out14RSS using different concrete compositions but under optimum moderation. These cases do not have stainless steel lining the walls.

Table 6-6. Different Concrete Composition under Optimum Moderation for Enrico Fermi and FFTF

Concrete Name	Case Name	Water Density (g/cm^3)	Enrico Fermi		MOX FFTF	
			k_{eff}	σ	k_{eff}	σ
Magnuson	Out14R05Mag	0.05	0.76717	0.00055	0.69373	0.00068
Oak Ridge	Out14R05OR		0.75406	0.00059	0.68169	0.00071
Regular	Out14R05Reg		0.74769	0.00060	0.67290	0.00059
Rocky Flats	Out14R05RF		0.75095	0.00060	0.67720	0.00068

6.5 DBE EVENTS

The cases presented in Table 6-7 correspond to different DBE events investigated under dry conditions. Out14R0 corresponds to an infinite array of canisters vertically oriented close to the concrete wall. Out14+1R0 corresponds to a single canister positioned horizontally over the infinite array of canisters vertically oriented (see Figure 5-3[a]). This case represents tipover/slapdown or drop events. Out14+1topR0 corresponds to a single canister standing up on top of the infinite array of canisters (see Figure 5-4[a]). Out14+1sideR0 corresponds to a single canister positioned horizontally on the floor, close to the infinite array of canisters (see Figure 5-3[b]). This case represents the tipover/slapdown or drop events. Out14+1tiltR0 corresponds to a single canister tilted against to the infinite array of canisters (see Figure 5-4[b]). The number zero at the end of each case name represents the water density used.

Table 6-8 presents the results for cases similar to those in Table 6-7, but under optimum moderation. In some cases, the stainless steel floor plate is not considered in the calculation because it is far from the fuel, therefore there is no effect on the k_{eff}. These cases names end in 05, indicating that a water density equal to 0.05 g/cm^3 is used in the calculation.

Table 6-7. k_{eff} for Various Events (Dry)

Cases Name	Reflected Enrico Fermi		Reflected FFTF	
	k_{eff}	σ	k_{eff}	σ
Out14R[a]	0.76008	0.00064	0.67845	0.00067
Out14+1R0	0.75696	0.00060	0.66688	0.00061
Out14+1topR0	0.75757	0.00059	0.68004	0.00106
Out14+1sideR0	0.76426	0.00055	0.66787	0.00064
Out14+1tiltR0	0.76284	0.00058	0.67828	0.00061

NOTE: [a] These are the results from Table 6-3 and Table 6-4 with stainless steel for E. Fermi and FFTF respectively.

Table 6-8. k_{eff} for Various Events under Optimum Moderation

Cases Name	Water density (g/cm^3)	Reflected Enrico Fermi		Reflected FFTF	
		k_{eff}	σ	k_{eff}	σ
Out14RSS05[a]	0.05	0.77219	0.00061	0.70028	0.0066
Out14+1R05		0.77416	0.00059	0.68917	0.00070
Out14+1topR05		0.77571	0.00055	0.70120	0.00064
Out14+1sideR05		0.78033	0.00060	0.68891	0.00070
Out14+1tiltR05		0.77520	0.00063	0.69965	0.00066

NOTE: [a] These are the results from Table 6-5 for E. Fermi and FFTF, respectively.

6.6 MAXIMUM NUMBER OF ROWS OF CANISTERS AGAINST A CONCRETE WALL

Table 6-9 shows different k_{eff} results for an infinitely long array of canisters varying the number of canisters for the depth of the array (see Figure 5-5). The number on the case name represents the number of canisters stored in the Y direction (depth), or the number of rows of canisters that can be stored along a concrete wall. There is no space between the canisters.

Table 6-9. Maximum Number of Canisters to be Lined Up in the Y Direction

Cases Name	Enrico Fermi		FFTF	
	k_{eff}	σ	k_{eff}	σ
Out3	0.84679	0.00058	0.79518	0.00063
Out4	0.89443	0.00057	0.86945	0.00066
Out5	0.91986	0.00056	0.91622	0.00074
Out6	0.93755	0.00057	0.95106	0.00066

6.7 CANISTERS INSIDE THE CASK

Table 6-10 and Table 6-11 show the k_{eff} results for a central canister surrounded by eight canisters under dry conditions. Table 6-12 and Table 6-13 show the same set of cases but with optimum moderation. Out9 has the reflected condition in the external cylinder, immediately around the eight canisters (see Figure 5-6). The same configuration as that for case Out9 is investigated considering a 10-cm thick stainless steel cask. This case is named Out9SS. Out9+1, similar to Out9, considers a single canister positioned horizontally over the circular array (see Figure 5-6). This case represents tipover/slapdown events.

Table 6-10. Cask Loaded with Dry Enrico Fermi Canisters

Case Name	Non-reflected		Reflected	
	k_{eff}	σ	k_{eff}	σ
Out9M0	0.57853	0.00053	0.89566	0.00054
Out9+1M0	0.57987	0.00053	-	-
Out9SSM0	0.71627	0.00060	0.84808	0.00056
Out9SS+1M0	0.71693	0.00061	-	-

Table 6-11. Cask Loaded with Dry MOX FFTF Canisters

Case Name	Non-reflected		Reflected	
	k_{eff}	σ	k_{eff}	σ
Out9M0	0.48987	0.00048	0.94296	0.00071
Out9+1M0	0.48949	0.00048	-	-
Out9SSM0	0.61546	0.00057	0.79560	0.00064
Out9SS+1M0	0.61605	0.00056	-	-

Table 6-12. Cask Loaded with Wet Enrico Fermi Canisters

Case Name	Water Density (g/cm^3)	Non-reflected		Reflected	
		k_{eff}	σ	k_{eff}	σ
Out9M05	0.05	0.60390	0.00064	0.84899	0.00059
Out9+1M05		0.61529	0.00059	-	-
Out9SSM05		0.70344	0.00062	0.79062	0.00053
Out9SS+1M05		0.70616	0.00056	-	-

Table 6-13. Cask Loaded with Wet MOX FFTF Canisters

Case Name	Water Density (g/cm^3)	Non-reflected		Reflected	
		k_{eff}	σ	k_{eff}	σ
Out9M05	0.05	0.51991	0.00062	0.80252	0.00070
Out9+1M05		0.53256	0.00060	-	-
Out9SSM05		0.61830	0.00058	0.72136	0.00066
Out9SS+1M05		0.62150	0.00063	-	-

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8. ATTACHMENTS

Table 8-1 contains a list of the attachments included in this calculation.

Table 8-1. List of Attachments

Attachment Number	Description	Pages
I	Compact Disc (CD) Containing the Output Files for the MCNP Calculations (Enrico Fermi, TRIGA, and FFTF)	N/A

Tables 8-2 through 8-4 present a description of the contents of Attachment I. The date and time stamp indicate when the file was transferred, not created.

Table 8-2. Files Contained in Attachment I Enrico Fermi Output

Name	Size (byte)	Date	Time
Table 6-1			
out0	321,489	10-06-00	11:21a
Table 6-2			
out14r0Mag	479,820	10-06-00	11:21a
out14r0OR	477,532	10-06-00	11:21a
out14r0Reg	475,726	10-06-00	11:21a
out14r0RF	476,476	10-06-00	11:21a
Table 6-3			
out14CC	484,991	10-06-00	11:22a
out14RCC	475,420	10-06-00	11:22a
out14CCRBS	486,673	10-06-00	11:22a
out14RCCRBS	479,112	10-06-00	11:22a
out14SS	485,357	10-06-00	11:22a
Out14RSS	481,723	10-06-00	11:22a
out14SSRBS	486,343	10-06-00	11:22a
out14RSSRBS	481,639	10-06-00	11:22a
Table 6-5			
out14R+CC	333,131	10-06-00	11:23a
out14RSS01	477,706	10-06-00	11:23a
out14RSS05	475,895	10-06-00	11:23a
out14RSS1	477,251	10-06-00	11:23a
out14RSS15	477,017	10-06-00	11:23a
out14RSS2	478,091	10-06-00	11:23a
out14RSS3	478,075	10-06-00	11:23a
out14RSS5	477,083	10-06-00	11:23a
out14RSS7	476,047	10-06-00	11:23a
out14RSS9	481,143	10-06-00	11:23a

Table 8-2. Files Contained in Attachment I Enrico Fermi Output (continued)

Name	Size (byte)	Date	Time
Table 6-6			
out14r05Mag	480,677	10-06-00	11:24a
out14r05OR	478,305	10-06-00	11:24a
out14r05Reg	473,991	10-06-00	11:23a
out14r05RF	479,609	10-06-00	11:23a
Table 6-7			
out14+1R0	483,259	10-06-00	11:24a
out14+1topR0	479,152	10-06-00	11:24a
out14+1sideR0	480,711	10-06-00	11:24a
out14+1tiltR0	483,161	10-06-00	11:24a
Table 6-8			
out14+1R05	483,720	10-06-00	11:25a
out14+1topR05	480,205	10-06-00	11:25a
out14+1sideR05	483,448	10-06-00	11:25a
out14+1tiltR05	480,992	10-06-00	11:25a
Table 6-9			
out3R	467,458	10-06-00	11:25a
out4R	468,814	10-06-00	11:25a
out5R	469,858	10-06-00	11:25a
out6R	471,214	10-06-00	11:25a
Table 6-10			
out9M0	460,969	10-06-00	11:26a
out9RM0	461,525	10-06-00	11:26a
out9+1M0	462,544	10-06-00	11:26a
out9SSM0	463,726	10-06-00	11:26a
out9RSSM0	463,970	10-06-00	11:26a
out9SS+1M0	466,309	10-06-00	11:26a
Table 6-12			
out9M05	461,692	10-06-00	11:26a
out9RM05	462,316	10-06-00	11:26a
out9+1M05	466,123	10-06-00	11:26a
out9SSM05	463,365	10-06-00	11:26a
out9RSSM05	463,395	10-06-00	11:26a
out9SS+1M05	468,568	10-06-00	11:26a

Table 8-3. Files Contained in Attachment I FFTF Output

Name	Size (byte)	Date	Time
Table 6-1			
out0	360,229	10-06-00	11:32a
Table 6-2			
out14r0Mag	357,794	10-06-00	11:32a
out14r0OR	355,880	10-06-00	11:32a
out14r0Reg	354,832	10-06-00	11:32a
out14r0RF	357,243	10-06-00	11:32a
Table 6-4			
out14CC	470,240	10-06-00	11:33a
out14RCC	467,926	10-06-00	11:33a
out14CCRBS	466,184	10-06-00	11:33a
out14RCCRBS	468,862	10-06-00	11:33a
out14SS	364,117	10-06-00	11:33a
Out14RSS	359,244	10-06-00	11:33a
out14SSRBS	360,160	10-08-00	12:00p
out14RSSRBS	361,344	10-06-00	11:33a
Table 6-5			
out14R+CC	25,039,555	10-06-00	11:34a
out14RSS01	359,926	10-08-00	12:00p
out14RSS05	363,670	10-08-00	12:00p
out14RSS1	363,560	10-08-00	12:00p
out14RSS15	360,382	10-08-00	12:00p
out14RSS2	357,708	10-06-00	11:33a
out14RSS3	357,380	10-06-00	11:33a
out14RSS5	357,178	10-06-00	11:33a
out14RSS7	357,178	10-06-00	11:33a
out14RSS9	356,769	10-06-00	11:33a
Table 6-6			
out14r05Mag	357,590	10-06-00	11:35a
out14r05OR	355,494	10-06-00	11:35a
out14r05Reg	355,150	10-06-00	11:35a
out14r05RF	357,354	10-06-00	11:35a
Table 6-7			
out14+1R0	369,079	10-06-00	11:35a
out14+1topR0	2,765,241	10-06-00	11:35a
out14+1sideR0	364,302	10-06-00	11:35a
out14+1tiltR0	364,105	10-06-00	11:35a

Table 8-3. Files Contained in Attachment I FFTF Output (continued)

Name	Size (byte)	Date	Time
Table 6-8			
out14+1R05	368,170	10-06-00	11:36a
out14+1topR05	360,341	10-06-00	11:37a
out14+1sideR05	363,023	10-06-00	11:36a
out14+1tiltR05	360,227	10-06-00	11:36a
Table 6-9			
out3R	360,578	10-06-00	11:39a
out4R	362,726	10-06-00	11:39a
out5R	366,301	10-06-00	11:39a
out6R	357,873	10-06-00	11:39a
Table 6-11			
out9M0	350,555	10-06-00	11:40a
out9RM0	364,008	10-06-00	11:40a
out9+1M0	353,825	10-06-00	11:40a
out9SSM0	350,731	10-06-00	11:39a
out9RSSM0	360,636	10-06-00	11:39a
out9SS+1M0	352,575	10-06-00	11:39a
Table 6-13			
out9M05	350,175	10-06-00	11:40a
out9RM05	353,043	10-06-00	11:40a
out9+1M05	1,413,397	10-06-00	11:40a
out9SSM05	565,504	10-06-00	11:40a
out9RSSM05	354,870	10-06-00	11:40a
out9SS+1M05	462,896	10-06-00	11:40a

Table 8-4. Files Contained in Attachment I TRIGA Output

Name	Size (byte)	Date	Time
Table 6-1			
out0	313,267	10-06-00	11:41a

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT SPECIAL INSTRUCTION SHEET *Complete Only Applicable Items*	1. QA: QA Page: 1 of: 1

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This is a placeholder page for records that cannot be scanned or microfilmed

2. Record Date 10/13/2000	3. Accession Number ATT TO MOL.20001024.0076
4. Author Name(s) JORGE E. MONROE-RAMMSY	5. Author Organization N/A

6. Title
CANISTER TRANSFER FACILITY CRITICALITY CALCULATIONS (ATTACHMENT I)

7. Document Number(s) CAL-EDC-NU-000005	8. Version REV. 00
9. Document Type CD-ROM	10. Medium DATA

11. Access Control Code
PUB

12. Traceability Designator
DC #26136

13. Comments
THIS IS A SPECIAL PROCESS DISC (ATTACHMENT I) AND CAN BE LOCATED THROUGH THE RPC

NOTE: SEE ATTACHMENT OF THE ELECTRONIC SOURCE FILE VERIFICATION FORM SATISFYING AP-17.1Q, REV. 1/ICN 2 { ELECTRONIC RECORDS }

DC# 26136

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ELECTRONIC SOURCE FILE VERIFICATION

QA: N/A

1. DOCUMENT TITLE: Canister Transfer Facility Criticality Calculations	
2. DOCUMENT IDENTIFIER: CAL-EDC-NU-000005	3. REVISION DESIGNATOR: 00

ELECTRONIC SOURCE FILE INFORMATION

4. ELECTRONIC SOURCE FILE NAME WITH FILE EXTENSION PROVIDED BY THE SOFTWARE: surface-00.doc		
5. DATE LAST MODIFIED: 10/13/2000	6. ELECTRONIC SOURCE FILE APPLICATION: (I.E., EXCEL, WORD, CORELDRAW) WORD	7. FILE SIZE IN KILOBYTES: 578kByte
8. FILE LINKAGE INSTRUCTIONS/INFORMATION: n/a		
9. FILE CUSTODIAN: (I.E., DC, OR DC APPROVED CUSTODIAN) DC	10. FILE LOCATION FOR DC APPROVED CUSTODIAN (I.E., SERVER, DIRECTORY)	
11. PRINTER SPECIFICATION (i. e., HP4SI) INCLUDING POSTSCRIPT INFORMATION (I.E., PRINTER DRIVER) AND PRINTING PAGE SETUP (I.E., LANDSCAPE, 11 X 17 PAPER) 4hp5si, Letter (8x11)		
12. COMPUTING PLATFORM USED: (I.E., SUN) IBM-PC compatible	13. OPERATING EQUIPMENT USED: (I.E., UNIX, SOLARIS) Windows	
14. ADDITIONAL HARDWARE/SOFTWARE REQUIREMENT USED TO CREATE FILE(S): N/A JMR 10/13/2000	15. ACCESS RESTRICTIONS: (IF ANY) N/A JMR 10/13/2000	

COMMENTS/SPECIAL INSTRUCTIONS

16. N/A
JMR
10/13/2000

CERTIFICATION

17. NAME (Print and Sign) Jorge E. Monroe-Rammsy			18. DATE: 10/13/2000
19. ORGANIZATION M&O	20. DEPARTMENT WPD	21. LOCATION/MAIL STOP 423/1000g	22. PHONE 295-3476

DC USE ONLY

23. DATE RECEIVED: 10/13/00	24. DATE REVIEWED: 10/24/2000	25. DATE FILES TRANSFERRED: 10/16/00
26. NAME (Print and Sign): Teri McCoy		27. DATE: 10/24/2000